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(54) **FQPSK-B VITERBI RECEIVER**

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(65) **Prior Publication Data**

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16, 2001.

(51) **Int. Cl.**
　　H03D 3/22　　　　(2006.01)
(52) **U.S. Cl.** **375/329**; 375/341
(58) **Field of Classification Search** 375/329,
375/341
See application file for complete search history.

(56) **References Cited**

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Vehicular Technology, vol. 43, Issue 3, Part 1-2, Aug. 1994
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(57)　　　　　　　**ABSTRACT**

An FQPSK-B receiver uses a simplified trellis system which
uses combinations of FQPSK-B waveforms to correlate
against an input signal. This enables reduction of the number
of correlators that are used and the number of comparisons
that are made by the correlators.

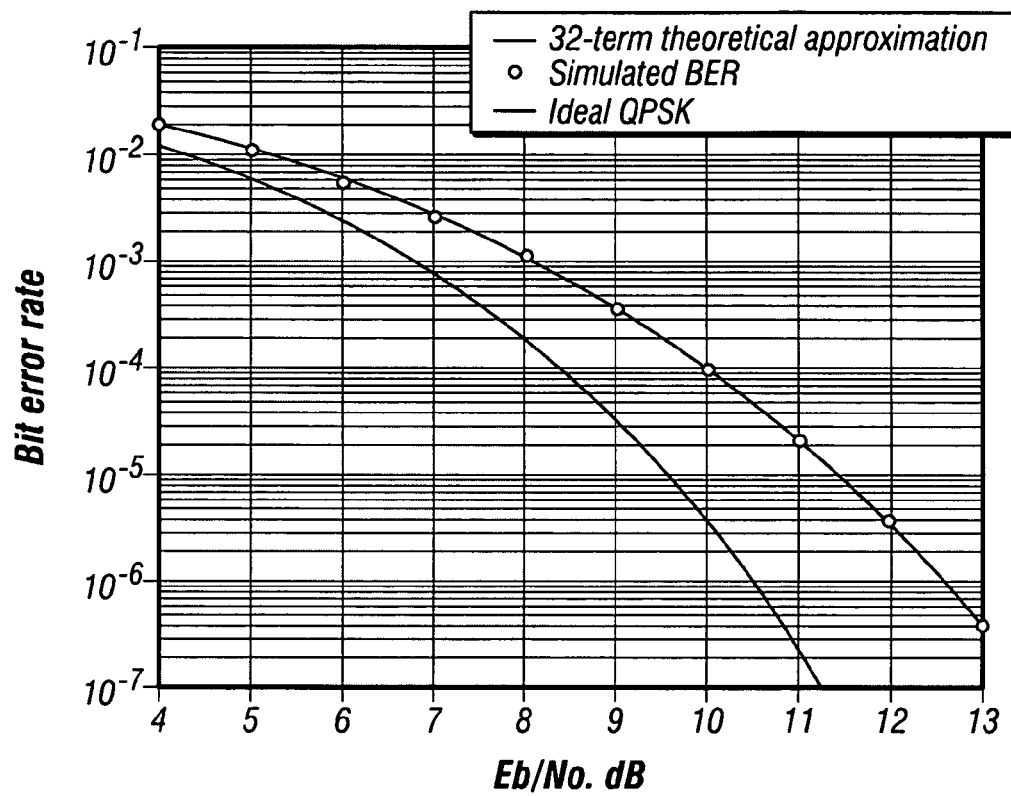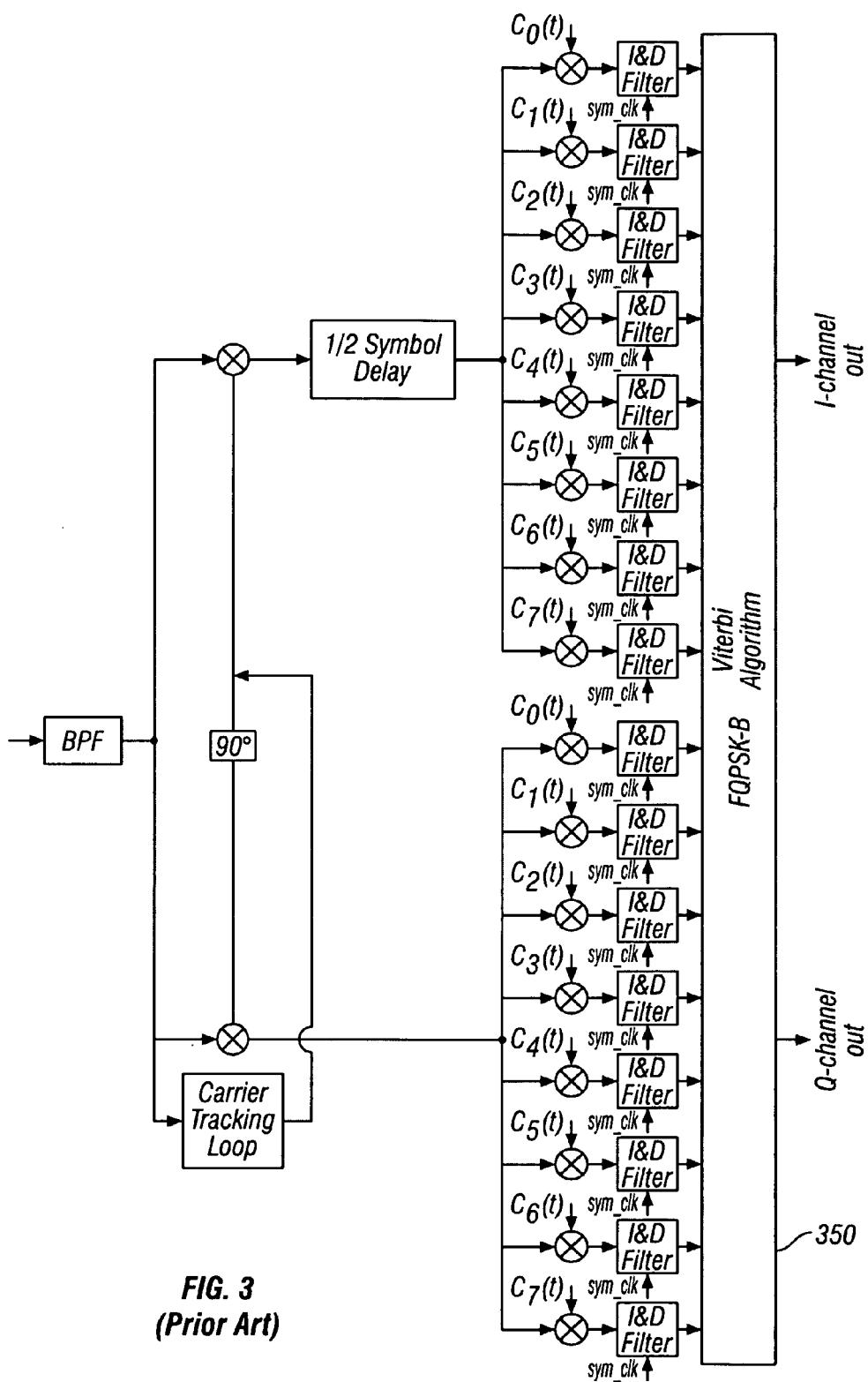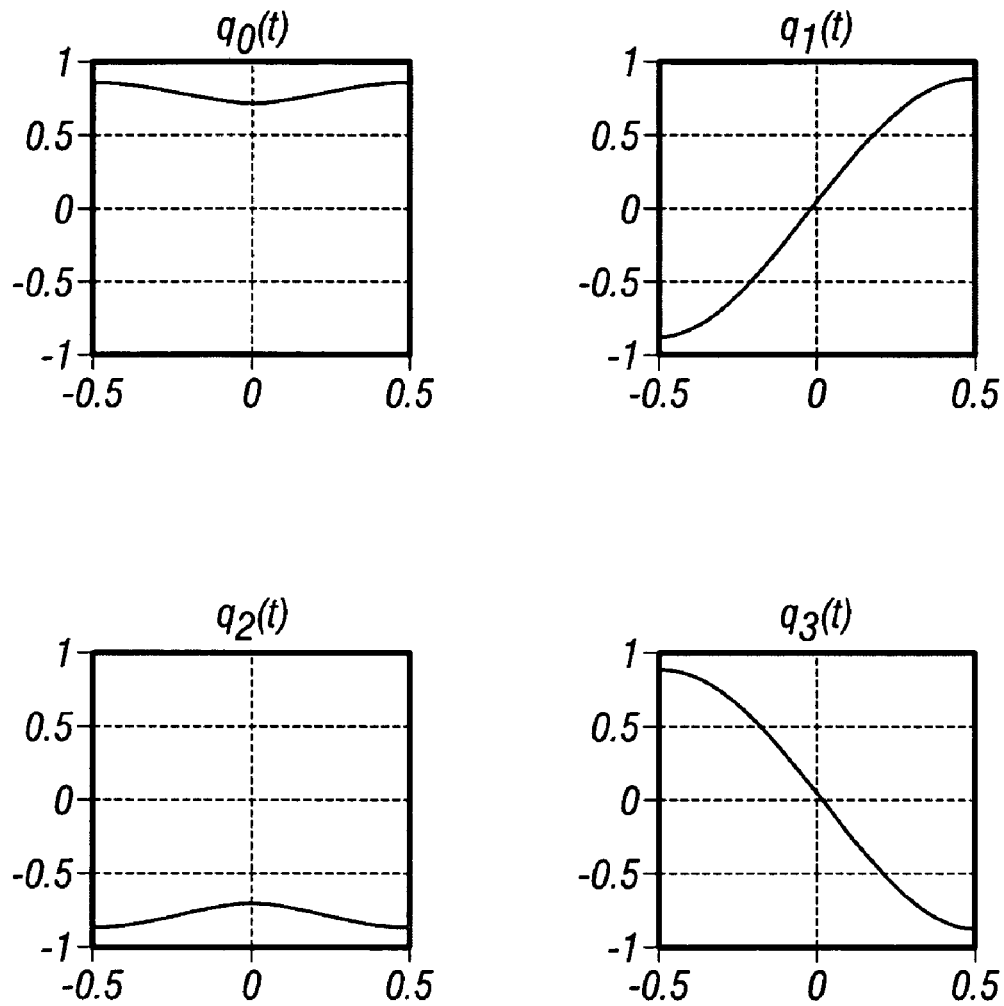**20 Claims, 5 Drawing Sheets**

$q_0(t)$

$q_1(t)$

$q_2(t)$

$q_3(t)$
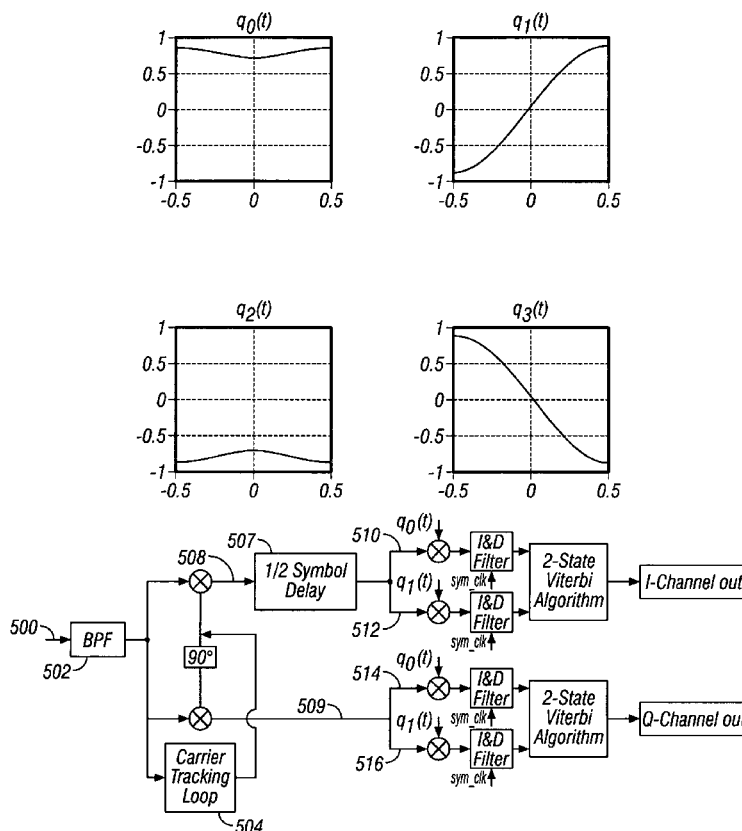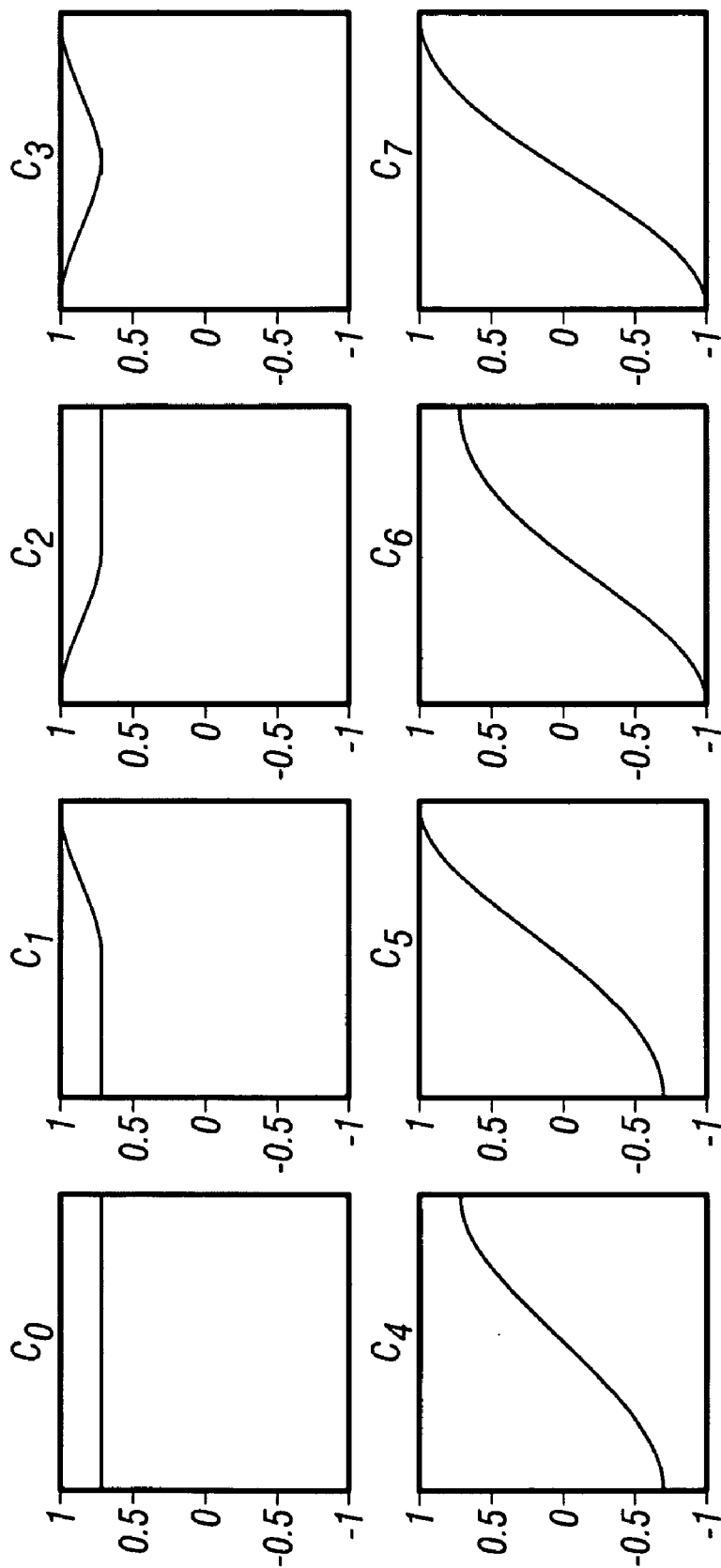
FIG. 1
(Prior Art)

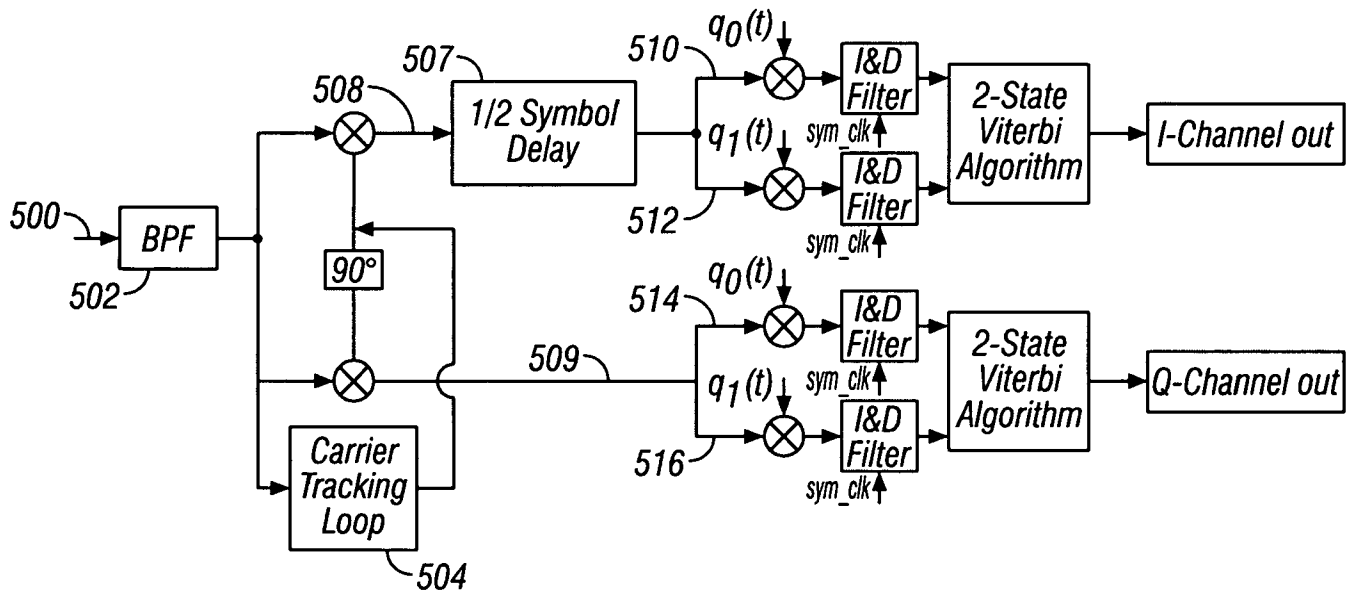FIG. 2

FIG. 3
(Prior Art)

FIG. 4

FIG. 5

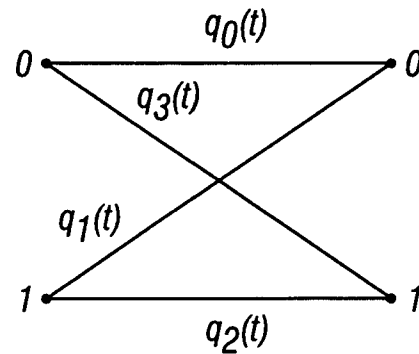**FIG. 6**

FQPSK-B VITERBI RECEIVER

CROSS-RELATED APPLICATION

The present application claims priority from provisional application No. 60/262,019, filed Jan. 16, 2001.

STATEMENT AS TO FEDERALLY-SPONSORED RESEARCH

The invention described herein was made in the performance of work under a NASA 7-1407 contract, and is subject to the provisions of Public Law 96-517 (U.S.C. 202) in which the contractor has elected to retain title.

The present application describes a special kind of Feher's Quaternary phase shift keying (FQPSK) Viterbi receiver.

BACKGROUND

Feher's Patent QPSK ("FQPSK") is a spectrally efficient form of offset QPSK modulation which uses pulse shaping in order to reduce spectral sidelobes, and cross-correlation between its in-phase ("I") and quadrature phase ("Q") baseband signals, in order to maintain a nearly constant signal envelope. These characteristics of FQPSK may make this format desirable for communication [s] in nonlinear, bandwidth-constrained channels.

A special form of FQPSK described in U.S. Pat. Nos. 4,567,602 and 5,491,457 , is known as FQPSK-B. This is a baseband filtered version of FQPSK which is more spectrally efficient than unfiltered FQPSK and thus is useful in limited bandwidth channels. However, the bandwidth limiting of FQPSK-B comes at the expense of bit error rate degradation caused by the introduction of intersymbol interference due to the baseband filtering. For example, a traditional receiver for FQPSK-B may have a bit error rate of 1.4 dB at 10^{-3}.

FQPSK-B signals may be demodulated using symbol-by-symbol detection. This kind of demodulator may be formed of a detection filter along with a sample and hold circuit.

While this forms a simple circuit, the demodulating circuit does not take sufficient advantage of the "memory" that is inherent in FQPSK-B signals. Because of this memory between signals, Viterbi demodulation may be optimum for this type of modulation. Viterbi modulation may provide better bit error rate performance.

A trellis-coded interpretation of FQPSK is known. The FQPSK signal is generated by transmitting one of 16 different shaped waveforms. The basic waveform shapes are shown in *Figure* 1. Eight unique waveforms are shown in FIG. 1. Eight other shapes, which are the negatives of those waveforms, are also used. These waveshapes characterize the 16 state trellis that represent the optimum Viterbi receiver for FQPSK (or FQPSK-B). A full-blown system of this type, while feasible, may be too complex for a commercial implementation.

A full-blown system of this type, however, may be too complex for a real implementation.

SUMMARY

The present application teaches a special Viterbi receiver that has reduced complexity but still has bit error rate advantages over a symbol-by-symbol detection type receiver. According to an embodiment, he waveforms forming the FQPSK-B signals are grouped in a special way to

create a simpler trellis, i.e., one with fewer states. This receiver will still provide significant gain over conventional FQPSK-B receivers, while reducing the complexity that would otherwise be inherent in an optimum FQPSK-B Viterbi receiver.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects will now be described in detail with reference to the accompanying drawings, wherein:

FIG. 1 shows waveforms for a conventional FQPSK system;

FIG. 2 shows a graph with a comparison of bit error rates for different FQPSK receivers;

FIG. 3 shows a block diagram of a conventional Viterbi receiver;

FIG. 4 shows a set of averaged waveforms for the Viterbi receiver;

FIG. 5 shows a block diagram an embodiment of a simplified FQPSK-B receiver; and

FIG. 6 shows a trellis diagram for the simplified FQPSK-B receiver.

DETAILED DESCRIPTION

The present invention defines a reduced complexity alternative system. This system may form a simplified FQPSK-B Viterbi receiver with a reduced number of correlators. For example, the receiver may have a factor of 4 fewer correlators in the receiver, and a factor of 8 fewer trellis branch computations.

In an embodiment, the 16 possible FQPSK-B waveforms are divided into 4 groups. Each group may include signals, for example, which have some similar characteristic. A FQPSK signal is received. This signal is correlated against the average of the waveforms in each group. The signals are appropriately grouped, as described herein, in a way that reduces the FQPSK trellis from a 16 state trellis with 4 transitions per state into two independent two-state trellises with only two transitions per state. Due to the similarity between the PQPSK-B waveforms, this reduced-complexity receiver only has a small E_b/N_0 penalty as compared with a full-blown Viterbi receiver. However, it offers significant performance gains as compared to the conventional FQPSK-B receiver. Special characteristics of this receiver are hence described.

A traditional commercial FQPSK-B receiver includes a sample and hold receiver that carries out symbol-by-symbol detection. The received signal is downconverted to baseband. The baseband signal is then filtered using a detection filter. The output of the detection filter is sampled, and a decision on the transmitted signal is made.

Intersymbol interference introduced by the input filter will increase the bit error probability of this receiver. FIG. 2 shows a comparison between the 32 term theoretical approximation of bit error probability, and the computer simulated results. This is further compared with the bit error probability of ideal QPSK in the figure.

A traditional FQPSK-B Viterbi receiver is shown in FIG. 3. This receiver may correlate the baseband received signal with the 16 FQPSK waveforms, and uses a Viterbi. Algorithm (VA) to perform trellis decoding. The Viterbi algorithm search along the transitions between states of the FQPSK trellis to find the path with the largest accumulated branch metric. The 16 Viterbi algorithm branch metrics Z_j are defined as follows:

$$Z_j = R_j - \frac{E_j}{2} \quad j = 0, \ldots, 15 \qquad (1)$$

where R_j is the correlation of the received signal and the jth waveforms, E_j is the energy in the jth waveform. The correlation values R_8 through R_{15} are obtained by taking the negatives of R_0 through R_7 respectively. For example, $R_0 = -R_8$. A total of 16 correlators are needed, with 8 correlators being needed for the in phase signals and 8 correlators being needed for the quadrature phase signals. The "Viterbi algorithm" block **350** may carry out the subtraction of $E_j/2$ from the value R_j.

A simplified FQPSK-B Viterbi receiver is described with reference to FIGS. **4** and **5**. In this embodiment, sets of waveforms are grouped together in order to create a reduced trellis. In the embodiment, the waveforms C_0, C_1, C_2 and C_3, as represented by the top row in FIG. **1**, are grouped into a first group. As can be seen by investigating these waveforms, each of the waveforms have "similar" properties. A second group is formed of the second row in FIG. **1**, including the waveforms C_4, C_5, C_6, and C_7. For example, C_0–C_3 each represent waveforms which have small or no deviation from a constant. Similarly C_4–C_7 represent waveforms which have small or no deviation from a sinusoid. That is, the waveforms within each group are spectrally similar, so that the combination (average) of these waveforms may also be spectrally similar to each of the waveforms being averaged. The third group of waveforms is formed of C_8–C_{11}, and a fourth group of waveforms is formed from C_{12}–C_{15}. This grouping enables the trellis-coded structure to be divided into two independent, in-phase and quadrature, two-state trellises.

FIG. **5** shows a block diagram of the modified receiver. The received signal **500** is filtered by **502** and demodulated by demodulator **504**. The demodulated signals include an in-phase signal **508** and quadrature signal **509**. The in-phase signal **508** is delayed by a half symbol by delay element **507**. The demodulated signal is correlated against the average of the waveforms in each group. Four correlators **510**, **512**, **514**, **516** are used for this correlation. The average values are shown in FIG. **4**, and obtained as:

Equations

Since q2 and q3 are respectively the negatives of q_0 and q_1. Only two q_2, q_3, q_0, q_1, correlators are needed for each of the I and Q channels. The same Viterbi algorithm metric is used in equation 1, except that E_j now represents the energy of the group average waveform $q_j(t)$.

FIG. **6** shows a trellis including group signals with two states and two transitions in each state. The dual Viterbi techniques for the I and Q channels can hence be combined into a single 4 state VA. Compared with the full Viterbi receiver, this simplified receiver may have 12 fewer correlators, and an eight fold reduction in the number of Viterbi algorithm computations per decoded bit.

Although only a few embodiments have been disclosed in detail above, other modifications are possible. All such modifications are intended to be encompassed within the following claims.

What is claimed is:

1. A receiver, comprising:
   a plurality of averaged waveforms, each said averaged waveform comprising an average of a plurality of FQPSK waveforms;

   a plurality of correlators, to correlate an input signal with each of said averaged waveforms of said plurality to form correlations; and
   a trellis decoder using said correlations to make decisions on the transmitted signals.

2. A receiver as in claim **1**, wherein said plurality of averaged waveforms each represent four FQPSK waveforms.

3. A receiver as in claim **1**, further comprising an input filter which filters an input signal.

4. A receiver as in claim **1**, further comprising a demodulator, receiving an input signal, and producing demodulated complex signals.

5. A receiver as in claim **4**, wherein said demodulated complex signals include an in-phase signal and a quadrature signal component.

6. A receiver as in claim **2**, wherein there are four of said correlators to correlate said FQPSK waveforms.

7. A receiver as in claim **1**, wherein each of said plurality of averaged waveforms include a plurality of basic FQPSK waveforms which have similar characteristics.

8. A receiver as in claim **7**, wherein each averaged waveform comprised a combination average of four FQPSK waveforms.

9. A receiver as in claim **1**, wherein said FQPSK waveform are FQPSK or FQPSK-B, waveforms.

10. A method, comprising:
    obtaining a plurality of basic waveforms which represent trellis waveforms for FQPSK or FQPSK-B;
    averaging groups of said plurality of waveforms to form averaged waveforms, wherein a number of said averaged waveforms is less than a number of said plurality of waveforms; and
    correlating an FQPSK-B input signal against said averaged waveforms to form a group of signals to be processed by a trellis decoder.

11. A method as in claim **10**, wherein said averaging groups comprises averaging tour of said PQPSK-B waveforms to form each averaged waveforms.

12. A method as in claim **10**, further comprising filtering an input signal, and wherein said correlating comprises correlating against a filtered input signal.

13. A method as in claim **10**, further comprising producing demodulated signals form input signals and a set of correlation from said demodulated signals.

14. A method as in claim **13**, wherein said demodulated signals include an in-phase signal and a quadrature signal.

15. A method as in claim **10**, wherein said correlating comprises using four of said correlators to correlated the demodulated inphase and quadrature input signal with said FQPSK-B waveforms.

16. A method as in claim **10**, wherein said plurality of averaged waveforms include a plurality of waveforms which have similar characteristics.

17. A method as in claim **10**, wherein each averaged waveforms comprise a combination of four FQPSK waveforms.

18. A receiver, comprising:
    a filter element, receiving an input PQPSK-B signal and producing a filtered FQPSK-B signal; and
    a Viterbi Algorithm receiver, producing demodulated signals based on said FQPSK-B input signals, wherein said Viterbi Algorithm receiver compares said filtered FQPSK-B signal with a plurality of averaged signals.

19. A method of receiving an FQPSK-B signal, comprising:

obtaining a plurality of basic FPQSK-B signals associated with modulation of an FQPSK-B signal;

averaging said plurality of basic FQPSK-B signals to form a plurality of averaged signals; and

comparing an input coded FQPSK-B signal with said plurality of averaged signals to carry out the modulation.

20. A method as in claim **19**, wherein there are 16 of said basic FQPSK-B signals, and wherein there are four of said averaged signals.

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